BBC RD 1975/23

1969 THE QUEEN'S AWARD TO INDUSTRY
1974 THE QUEEN'S AWARD TO INDUSTRY

RESEARCH DEPARTMENT **REPORT**

DIGITAL SOUND: baseband filtering to improve the fading margin for 13-channel system operating over existing f.m. links

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THE BRITISH BROADCASTING CORPORATION **July 1975**

BBC RD 1975/23
UDC 621.376.56
534.86
621.391.822

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Summary

In order to realise as rapidly as possible the potential advantages of pulse code modulation, microwave frequency-modulation links, originally intended for monochrome video signals, are being used to distribute sound programmes to transmitters by multiplexed p.c.m. signals. However, for instrumental reasons the maximum carrier-deviation adopted for p.c.m. data must in some cases be reduced below that used for video (8 MHz peak-to-peak).

This report deals principally with means of recovering the loss of effective fading-margin caused by reduced deviation, and includes the results of measurements carried out on a Post Office link and on a laboratory simulation. It is concluded that the fading margin which applies when deviation is reduced by 8 dB can be restored substantially, to within 1 dB of the figure for full deviation, by means of a suitable baseband low-pass filter at the receiving terminal.

Issued under the authority of

Head of Research Deparment

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

July 1975

EL-108

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1. Introduction

Since the BBC adopted, in the early years of radio, the practice of 'simultaneous broadcasting' – i.e., radiation of the same radio programme from a number of transmitters simultaneously – sound signals have normally been distributed between broadcasting centres by baseband 'music-lines' rented from the Post Office. At present, the BBC's requirement for sound circuits is increasing – due largely to the expansion of stereophonic broadcasting; however, Post Office development plans for the national telephone network of the future assume digital, rather than analogue, operation – so conventional music-lines will become less readily available. Further, the problems of matching two baseband music-lines for stereophony can be severe, and the performance of such circuits over long distances often leaves something to be desired, even for monophony. For these reasons alternatives to the baseband music-line as a means of distributing sound programmes for broadcasting have been closely studied in recent years.

In the BBC particular attention has been given to pulse-code modulation (p.c.m.) techniques. Means have been devised to code sound-signals in p.c.m. form[1,2] and to multiplex groups of high-quality p.c.m.-sound signals for distribution throughout the country.[3,4] Until such time as a suitable Post Office digital-data network is available, the benefits of digital techniques can be obtained by distributing multiplex-p.c.m. signals on existing bearer circuits – in particular on super-high-frequency/frequency-modulation (s.h.f./f.m.) links primarily intended for monochrome, 625-line, video signals. A data rate of 6.336 Mbit/s was agreed in 1970 for this application, and p.c.m. multiplex equipment, providing 13 high-quality sound channels, was developed by the BBC.[5]

This arrangement is in use on BBC s.h.f. links, taking stereophonic sound signals to the very-high-frequency/frequency-modulation (v.h.f./f.m.) transmitters at Wrotham, Sutton Coldfield and Holme Moss.

In extending the service to Scotland, using Post Office s.h.f. video links which will also carry other traffic, the Post Office have observed that there is a considerable change in the r.f. spectrum when video signals are replaced by p.c.m.-sound data at the normal deviation, 8 MHz peak-to-peak; the energy near the carrier rest-frequency is reduced, while that near the edges of the band is increased. In consequence, some types of link equipment, which use narrow-band carrier-detector circuits, indicate carrier failure prematurely; further, the risk of interfering with traffic in adjacent channels is increased. Both these effects could be eliminated by changes in the f.m. carrier apparatus – but only by modifying Post Office permanent-link equipment.

An alternative approach is simply to reduce the f.m. carrier deviation for p.c.m.-sound transmission to a value which gives an acceptable r.f. energy distribution. This method has been proposed by the Post Office, who have suggested that carrier deviation should be reduced by 8 dB. Though this solution has the advantage that it needs no modification of permanent-link equipment, it has the disadvantage that it reduces the baseband-data signal-to-noise ratio at the receiving terminal and thus the effective fading margin of the link. In a preliminary field measurement* on one P.O. link carrying p.c.m.-sound data it was found that 8 dB reduction of deviation reduced the r.f. fading margin by a similar amount, about 7 dB.

Even though some paths have reserve links that are automatically switched in to combat deep fades on the working channel, it is obviously desirable to keep the fading margin as high as possible on the s.h.f. links used for p.c.m. sound-signal distribution. This report describes an investigation into means of recovering the effective fading-margin on an s.h.f. link used for p.c.m. sound, where that margin has been degraded by reducing the carrier deviation. It gives the results of measurements on a laboratory simulation of an s.h.f. link and on a real Post Office bearer circuit.

2. Characteristics of an f.m. system for p.c.m.-sound transmission

The Post Office f.m. links now being used for p.c.m. multiplex sound-signal distribution are of a type known as 'Tariff V1 circuits', originally intended for monochrome television signals. They operate in the 2 GHz, 6 GHz or 11 GHz frequency bands, with a separation of 20 MHz to 28 MHz between the centre frequencies of adjacent channels. The baseband performance of the circuit is specified to a frequency of 5 MHz, but, typically, the bandwidth extends to about 8 MHz and the results of the preliminary tests suggest that no significant reduction of this bandwidth was made prior to decoding. The i.f. bandwidth of these links is specified in terms of the 0·1 dB attenuation points to be ± 8 MHz (i.e. 16 MHz overall). Where the system noise is being considered, the –3 dB bandwidth is the significant parameter, although this is not specified for the Tariff V1 Post Office links. The laboratory simulation of an f.m. link, described in Section 4, incorporated in effect, an i.f. filter with a bandwidth of 20 MHz to the –3 dB points.

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*Carried out by staff of Communications Department and Designs Department of the BBC, in co-operation with staff of the Post Office.

Pre-emphasis and de-emphasis are used on the Post Office links, normally in accordance with CCIR recommendations,[6] and the deviation sensitivity is 8 MHz peak-to-peak for a 1-volt peak-to-peak sinewave input at the frequency corresponding to the 0 dB point on the CCIR 625-line pre-emphasis characteristic. The same parameters were adopted for the f.m. modem used to simulate an s.h.f. link for the present work.

A p.c.m. system is said to have failed when the digit error rate in the decoding process has reached such a level that the reproduced programme suffers unacceptable impairment. The characteristics of a p.c.m. system are such that it will tolerate a considerable degradation of the baseband signal-to-noise ratio before any impairment of the decoded signal occurs. Once the decoded signal shows impairment, it deteriorates very rapidly as the baseband signal-to-noise ratio worsens. Thus a p.c.m. signal sent over an f.m. link can give reliable, consistently high-grade results despite deep fading, provided that the system is designed to ensure that a certain minimum baseband signal-to-noise ratio is maintained. The signal-to-noise ratio required at the output of the link is considerably lower than that which would be required for television purposes.

In order to ensure that the baseband signal-to-noise ratio is satisfactory, it is important that sufficient deviation is used on the link. The amplitude of the baseband signal at the output of the link demodulator depends upon the carrier deviation, and if the latter is too low 'modulation failure' occurs when the demodulated noise level becomes comparable with the baseband-signal level. It is also important to ensure that the amplitude of the received carrier is sufficient to avoid 'carrier failure'. This effect occurs when the peaks of noise exceed the carrier amplitude, causing an impulsive type of noise to appear in the demodulated baseband-signal. Carrier failure occurs relatively abruptly, as the received carrier-to-noise power ratio is reduced, at a point of transition from continuous noise to impulsive noise in the baseband, known as the 'f.m. improvement threshold'. A more detailed treatment of p.c.m./f.m. link requirements is given in an earlier report.[7]

With the f.m. link operated normally, at full deviation, the effects of modulation failure and of carrier failure set substantially the same limit to the depth of fade which the p.c.m. system will tolerate. At the reduced deviation required by the Post Office, however, the limiting factor is modulation failure. This is significant because, if it is possible to improve the baseband signal-to-noise ratio after the demodulator (i.e. delay the onset of modulation failure) the fading margin can be improved. The fading margin is determined ultimately by carrier failure.

The f.m. improvement threshold, defined by the noise considerations outlined above, is a fundamental property of an f.m. system, and is not the same as the 'carrier failure point' defined by an alarm circuit on the Post Office links. The 'carrier failure alarm', which is built into the Post Office links, works by detecting the reduction of the energy near the carrier rest-frequency below a preset value during deep fades. A locally-generated plain carrier is injected into the demodulator during a deep fade to prevent successive links amplifying and re-transmitting noise. The alarm can also switch the signal to a protection channel (spare link) if one is available, and it is normally set to operate when a fade of 30 to 35 dB is experienced, as this depth of fading would make the link unacceptable for monochrome television signals.

3. Recovery of fading margin lost through deviation reduction

3.1 General

The possible measures that could be employed to avoid undue loss of fading margin fall into three categories:

(a) Modifications to the RF link equipment
(b) Transmitter baseband-processing
(c) Receiver baseband-processing

Obviously a change made in any one area might have implications on the other areas.

3.2. Modifications to the RF link equipment

The most obvious action would be a request to the Post Office to alter their 'carrier failure' detector, combined possibly with the provision of a specification of the allowable sideband-energy 'spillover' into adjacent channels; it could then be ascertained whether the digitally-modulated f.m. signal (at a peak-to-peak deviation of 8 MHz) in fact violated that specification.

If necessary a bandpass filter could be inserted immediately following the frequency modulator to suppress all adjacent channel components.

However, a reduction in deviation does not automatically imply a reduction in the system noise-performance, and hence in the fading margin. From Fig. 3 of Ref. 7 it may be seen that a digital f.m. link performs equally well (in terms of the carrier power required for an error-rate of 1 in 10^3) with 8 MHz and 4 MHz peak-to-peak carrier deviations; this, of course, holds only if appropriate receiver filtering is applied to the signal to remove noise at those frequencies not occupied by the f.m. signal spectrum. Therefore, it seems likely that a certain amount of the fading margin lost due to a reduction in deviation could be recovered by bandpass r.f. filtering at the receiver.

Whilst it seems unlikely that a narrower r.f. filter, at either the transmitter or the receiver, would cause unacceptable distortion to the baseband digital signal, it might have an adverse effect on the performance if the same link were sometimes required to carry analogue video signals. In any case, implementation of any of these techniques would require considerable modification of Post Office permanent link equipment; since this is impracticable, r.f. filtering was not considered further and effort was concentrated on techniques in which the processing was carried out at baseband frequencies.

3.3 Transmitter baseband-processing

A widely used method of controlling the baseband spectrum of a signal is to employ some form of multi-level code; for example, a bipolar-coded signal with no d.c. component. Although this approach could improve the f.m. spectrum to a limited extent, changing from a binary to a multi-level signal immediately results in a significant reduction of the noise margin.

The high-frequency pre-emphasis which is usually employed on Tariff V1 circuits is a form of transmitter baseband-processing. A mild form of pre-emphasis is unlikely to affect the amount of r.f. energy in the vicinity of the f.m. carrier. The complementary receiver de-emphasis would apply some attenuation to the high-frequency baseband noise; as the noise on a demodulated f.m. signal is triangular, the effect of the de-emphasis network would be an overall reduction in noise power. In fact, insertion of a network with the CCIR emphasis characteristic[6] was shown in the laboratory simulation (see Section 4.3.1) to yield a worthwhile improvement of about 2 to 3 dB in the fading margin.

3.4 Receiver baseband-processing

As hinted in the Section 3.3, the key to any major improvement in the fading margin lies in seeking benefit from the fact that the noise spectrum from a frequency demodulator is triangular; this is still the case when the carrier level is reduced to a point where the baseband bit-error-rate reaches a value of 1 in 10.^{3}

For the BBC multiplex p.c.m.-sound system, the transmitted pulse is raised-cosine in shape, extending over two clock periods, $2T$, where T is the clock period. Such a '$2T$ pulse' has an energy spectrum which falls with increasing frequency (as shown in Fig. 2 of Ref. 7) at least up to clock frequency $1/T$. As the prevailing triangular noise characteristic rises with increasing frequency, it seems reasonable to assume that some form of filtering which has a rising attenuation/frequency characteristic would, if applied to the demodulated signal, effect some improvement.

In the design of a suitable filter, phase response is important as well as amplitude response, since an arbitrary phase response could give rise to severe intersymbol interference in the received pulse-train.

As a first consideration, it should be noted that the transmitted pulses will not have any significant energy above the clock frequency, 6·336 MHz, which here is numerically equal to the bit-rate. As the receiver has a nominal output bandwidth of 8 MHz, using a 6·336 MHz low-pass filter should improve the signal-to-noise ratio by 3·04 dB. This calculation assumes that pre- and de-emphasis is not employed, so that the noise spectral power density is of the form $N(f) = af^2$, where a is a constant and f is the baseband frequency; hence the noise power in a frequency region 0 to f_1 is proportional to f_1^3.

It has been noted[7] that 99% of the energy of a $2T$ raised-cosine pulse is contained in the spectrum below 0·7 of the clock frequency; therefore, it is assumed that the insertion of a low-pass filter corresponding to that frequency (4·44 MHz) would not give rise to much intersymbol interference; such a filter would reduce the (triangular) noise power by 7·69 dB, again assuming a nominal receiver bandwidth of 8 MHz. A simple 4·5 MHz low-pass filter with group-delay correction was therefore chosen as one experimental filter.

The choice of cut-off frequency of a receiver low-pass filter is a compromise between noise rejection over the higher baseband-frequencies and the avoidance of undue intersymbol interference as the filter bandwidth is reduced.

An 'optimum' receiver-filter is required to cause no intersymbol interference to the pulse train and to apply maximum attenuation to the noise power. The former requirement is known as Nyquist's criterion[8] and imposes some constraints on the form of the overall response of the filters in the system; the remaining response 'variables' are then chosen to provide maximum attenuation to noise of a given spectrum.

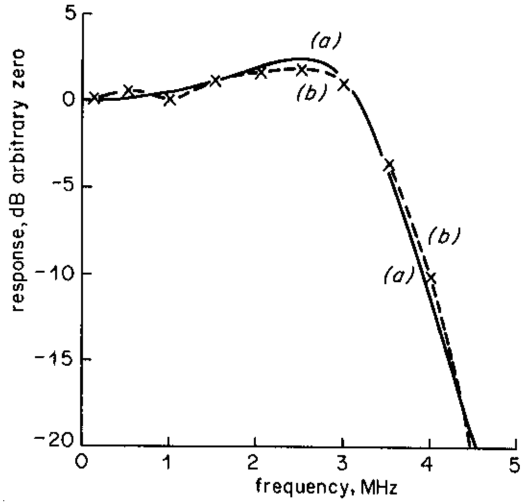

Fig. 1 - Optimised low-pass filter: performance
(a) Desired (b) Realised

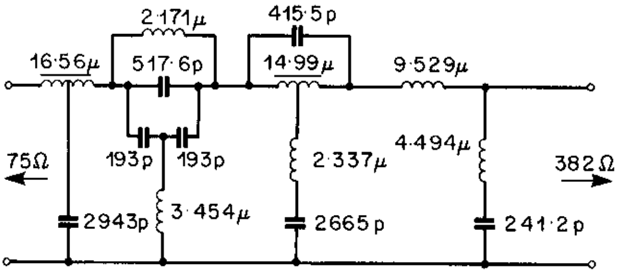

Fig. 2 - Optimised low-pass filter: practical circuit used

A method of computing the frequency response of the optimum filter for a generalised transmitted pulse-shape[8] in the presence of white noise has been extended to the case where the noise spectrum was arbitrary. The amplitude/frequency filter characteristic for a $2T$ (raised-cosine) pulse and triangular (or differentiated-white) noise is shown in Fig. 1, curve (a). The phase response of the optimum filter is zero, or exactly linear. The effect of this filter was calculated to be a reduction in the noise power by 9·3 dB compared with an 8 MHz low-pass filter, and by about 1·6 dB compared with a 4·4 MHz low-pass filter.

To assist in the experimental investigation a practical filter was designed* and built. The circuit, shown in Fig. 2, gives the computed values of the components; in practice a 1% tolerance was applied, a fine adjustment of inductor values being used to set the resonances of the various LC circuits to the nominal values. The amplitude/frequency response of the practical filter is shown in Fig. 1, curve (b); the group-delay characteristic was flat within ± 25 ns up to about 4 MHz. Since the filter was of a relatively simple design, an additional low-pass filter was required to maintain the attenuation at high frequencies.

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*Computer work carried out by D.C. Broughton of Designs Department, BBC.

4. Laboratory simulation of multiplexed p.c.m.-sound transmission on f.m. bearer circuits

4.1 Apparatus

The apparatus used for the laboratory simulation comprised an f.m. modem with means of varying the carrier-to-noise ratio, equipment to generate and to recover simulated p.c.m.-sound data, and apparatus, to detect and to count errors in the data stream after recovery. A block-schematic diagram of the experimental arrangement is shown in Fig. 3.

Noise was injected into the f.m. signal by a generator consisting of a diode noise-source and amplifiers, and care was taken to ensure that sufficient carrier level existed at the input to the 70 MHz demodulator to maintain effective limiting. No i.f. filters were available with sufficiently low group-delay distortion characteristics (± 2 ns over the filter passband) to simulate accurately the response of the i.f. filters used by the Post Office. As the only function of the filter in this work was to define the noise bandwidth of the system, it was placed in the noise amplifying chain where the group-delay characteristics would not introduce distortion into the f.m. signal.

A bolometer type of r.f. power meter was used to measure carrier power and noise power.

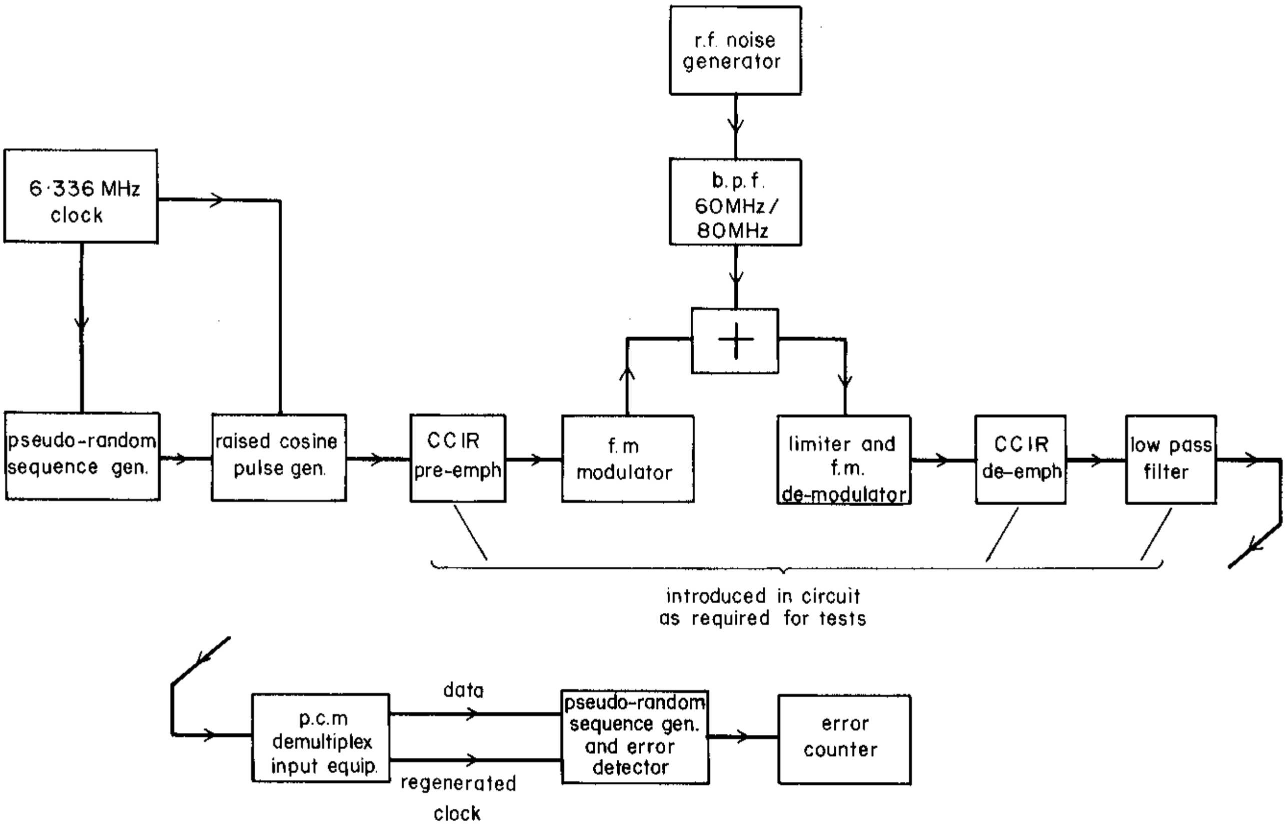
r.f. noise generator
b.p.f. 60MHz/80MHz
+
6·336 MHz clock
pseudo-random sequence gen.
raised cosine pulse gen.
CCIR pre-emph
f.m modulator
limiter and f.m. de-modulator
CCIR de-emph
low pass filter
introduced in circuit as required for tests
p.c.m demultiplex input equip.
data
regenerated clock
pseudo-random sequence gen. and error detector
error counter

Fig. 3 - Transmission of multiplexed p.c.m.-sound data on f.m. bearer: laboratory simulation apparatus

It was not practicable in the laboratory investigation to provide the analogue-to-digital converters and other equipment necessary to generate a 6·336 Mb/s data stream derived from 13 sound-signals as is done in the operational BBC system. Such a data stream was therefore simulated by a pseudo-random sequence of raised-cosine pulses at 6·336 Mb/s. The sequence generator was arranged so that the sequence length was equal to the frame length adopted for the BBC 6·336 Mb/s multiplex system – and further, that the test sequence contained the framing pattern appropriate to the system.

Fortunately, de-multiplex input equipment designed for the 6·336 mb/s system was available for the investigation, and was used to recover data and to regenerate a clock signal from the data stream after demodulation. A second pseudo-random sequence generator, having the same sequence as the source generator, was used to detect data errors, and the effective error rate was then measured on a counter.

The apparatus described above was used, in the first place, to study the effect of deviation and of emphasis on the r.f. energy spectrum of the transmitted signal and, in

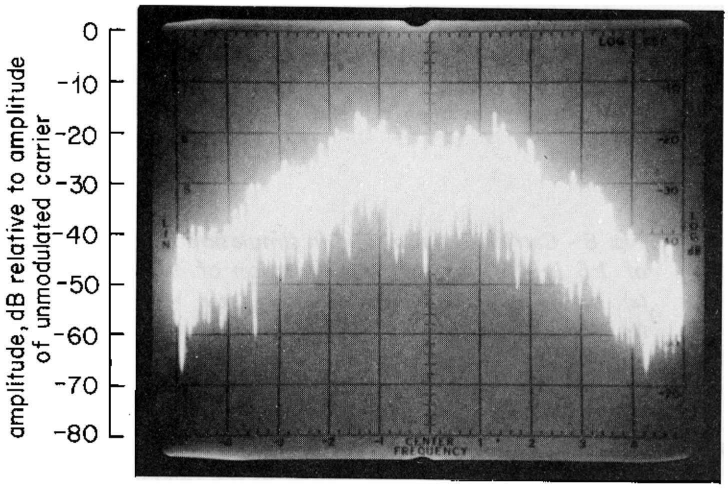

Fig. 4 - R.F. spectrum of the p.c.m./f.m. signal at full deviation, with CCIR 625-line pre-emphasis

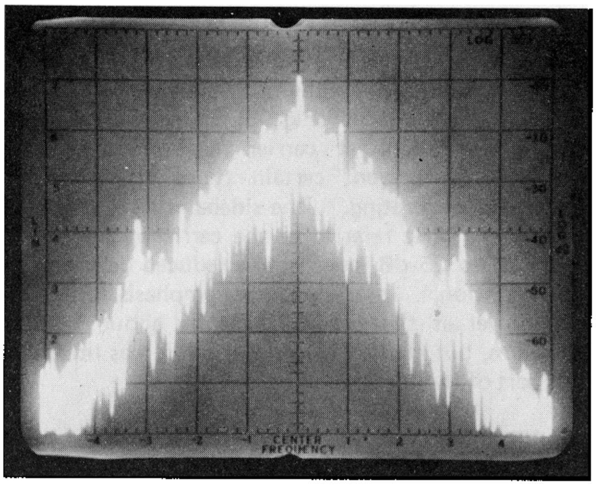

Fig. 5 - R.F. spectrum of the p.c.m./f.m. signal at 8 dB below full deviation, with CCIR 625-line pre-emphasis

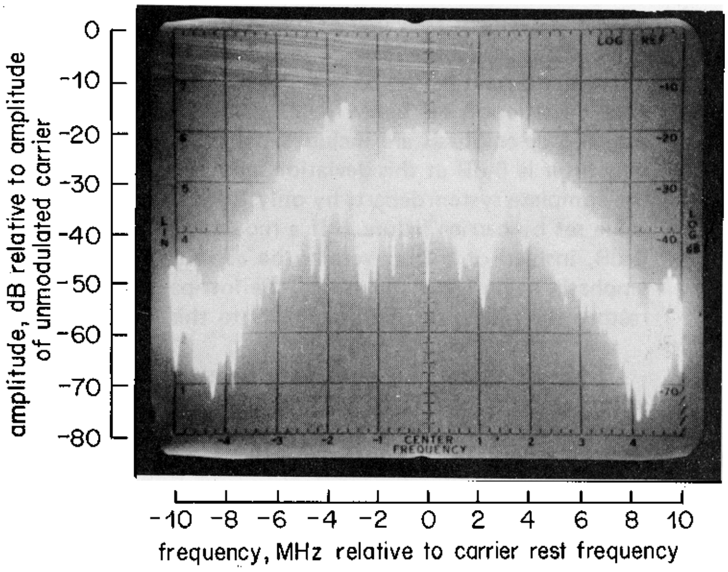

Fig. 6 - R.F. spectrum of the p.c.m./f.m. signal at full deviation, without pre-emphasis

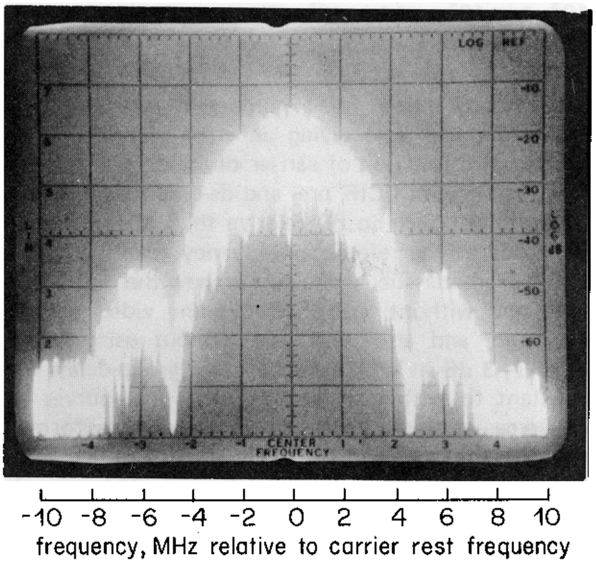

Fig. 7 - R.F. spectrum of the p.c.m./f.m. signal at 8 dB below full deviation, without pre-emphasis

the second place, to investigate the variation of fading margin with deviation and with baseband low-pass filtering. These investigations are described in the following sections.

4.2 R.F. energy spectrum

A series of preliminary tests was conducted in order to show the effects of pre-emphasis and of changing the deviation on the spectrum of the digital f.m. signals. Figs. 4 and 5 show the spectra obtained at the output of the modulator with CCIR 625-line video pre-emphasis[6] at full deviation (8 MHz peak-to-peak for a 1-volt sinewave modulating-signal at the 0 dB reference frequency on the pre-emphasis characteristic) and at a deviation 8 dB below the full value respectively; Figs. 6 and 7 show the spectra obtained without pre-emphasis, at full and −8 dB deviation respectively. The spectrum analyser i.f. bandwidth was 30 kHz for these pictures, and the 0 dB reference level on the graticule corresponded to the amplitude of the unmodulated carrier.

The spectrum for the pre-emphasised signal obtained at reduced deviation (Fig. 5) shows quite clearly the strong component at carrier rest frequency which is necessary to prevent certain types of 'carrier failure' alarm from operating. The sideband level at the channel edge (± 10 MHz relative to the carrier rest frequency) is some 20 to 25 dB lower at the reduced deviation than at full deviation. Insertion of pre-emphasis raises the sideband level at the channel edge by about 5 dB at full deviation, but at the reduced deviation, has little effect on this part of the spectrum.

4.3 Effects on fading margin of baseband low-pass filtering

4.3.1 4·5 MHz low-pass filter

In the laboratory investigation of the effect of baseband filtering, the f.m. carrier-to-noise ratio was measured at various levels of deviation for data error rates of 1·5 in 10^3, 1 in 10^5 and 1 in 10^6. The low-pass filter was inserted after f.m. demodulation (see Fig. 3).

Fig. 8 shows, for a number of test conditions, the carrier-to-noise ratio giving an error rate of 1·5 in 10,^{3} plotted as a function of carrier deviation. For those tests carried out with CCIR pre- and de-emphasis in circuit, the deviation is given in dB relative to 8 MHz peak-to-peak, measured at the reference frequency (0 dB point) of the CCIR characteristic. The curves show the results obtained with and without the CCIR 625-line video pre- and de-emphasis, and also with and without using a low-pass filter (−3 dB at 4·5 MHz) having a group-delay which is constant to within about ± 50 ns. The curves tend to converge at high deviation where the performance is ultimately determined by carrier failure rather than modulation failure as discussed in Section 2. At lower values of deviation the curves diverge, and, for deviation 8 dB below 8 MHz peak-to-peak, the increase in carrier-to-noise ratio for the specified error rate – equivalent in the simulation to reduction of fading margin on a link – is 9 dB for the test condition having neither baseband filter nor pre- and de-emphasis, and 6·5 dB with pre- and de-emphasis included. The latter result is in reasonable agreement with the 7 dB reduction in fading margin noted in the field measurement on a link at the same level of deviation, as mentioned in Section 1.

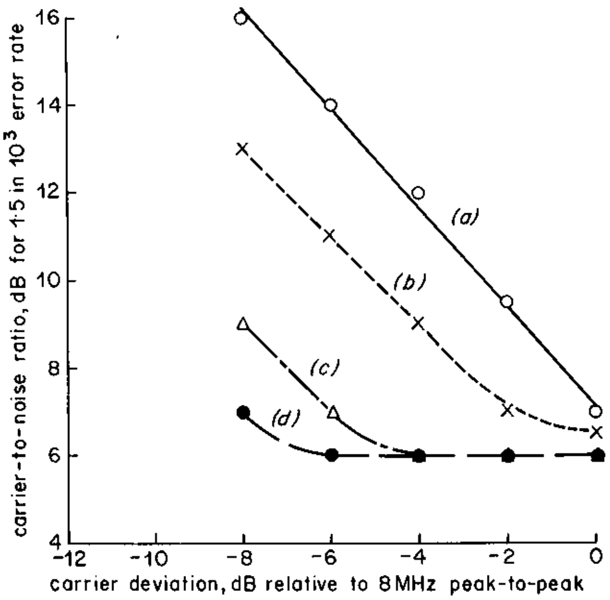

Fig. 8 - Carrier-to-noise ratio in simulation for an error rate of 1·5 in 10,^{3} plotted as a function of carrier deviation

(a) No pre- and de-emphasis, no low-pass filter

(b) With CCIR 625-line pre- and de-emphasis, no low-pass filter

(c) No pre- and de-emphasis, with 4·5 MHz low-pass filter

(d) With CCIR 625-line pre- and de-emphasis, and with 4·5 MHz low-pass filter

The effect of pre- and de-emphasis is favourable throughout – improving the fading margin by 2 to 3 dB except where performance is determined by carrier failure. The improvement provided by the 4·5 MHz low-pass filter is more dramatic; the filter gives a gain of 7 dB when introduced in a circuit having no pre- and de-emphasis, operating at a deviation 8 dB below 8 MHz peak-to-peak. When pre- and de-emphasis are included the gain due to the low-pass filter is 6 dB at this deviation, and the performance of the complete system departs by only 1 dB from the limiting value set by carrier failure. If a reduction of deviation of 6 dB, instead of 8 dB, were to be adopted, pre- and de-emphasis being retained, use of the low-pass filter would restore the fading margin practically to this limiting value.

Fig. 9 shows the results of measurements made at error rates of 1 in 10^5 and 1 in 10^6, with pre- and de-emphasis in circuit; the corresponding curves for an error rate of 1·5 in 10,^{3} already given in Fig. 8, are repeated for comparison. It will be seen that the measured improvements of fading margin obtained with the low-pass filter are substantially independent of the error rate.

Also indicated in Fig. 9 are the calculated values of carrier-to-noise ratio* at the f.m. noise-improvement thres-

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*calculated by R.V. Harvey from data given in an earlier report.[7]

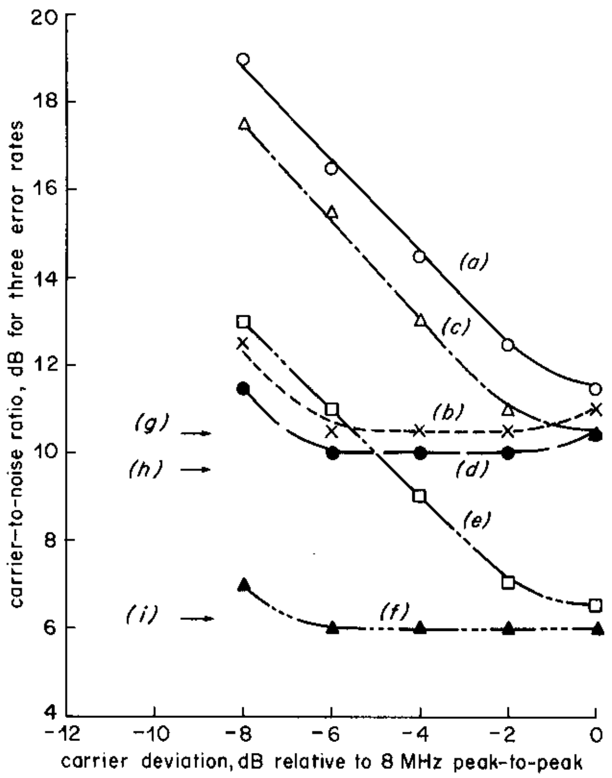

Fig. 9 - Carrier-to-noise ratio in simulation for error rates of 1·5 in 10,^{3} 1 in 10,^{5} and 1 in 10,^{6} plotted as a function of carrier deviation. CCIR pre- and de-emphasis in circuit.

(a). Error rate 1 in 10,^{6} no low-pass filter
(b) Error rate 1 in 10,^{6} with 4·5 MHz low-pass filter
(c) Error rate 1 in 10,^{5} no low-pass filter
(d) Error rate 1 in 10,^{5} with 4·5 MHz low-pass filter
(e) Error rate 1·5 in 10,^{3} no low-pass filter
(f) Error rate 1·5 in 10^3, with 4·5 MHz low-pass filter
(g) Improvement threshold calculated for error rate of 1 in 10^6
(h) Improvement threshold calculated for error rate of 1 in 10^5
(i) Improvement threshold calculated for error rate of 1·5 in 10^3

hold when 'carrier failure' occurs, for the specified error-rates. The theoretical and practical-simulation results show good agreement.

4.3.2 'Optimum' low-pass filter

A few brief tests were carried out in the laboratory simulation using the 'optimum' low-pass filter arrangement described in Section 3.4 The results indicated that the arrangement gave slightly better performance than the 4·5 MHz low-pass filter for test conditions well away from the noise-improvement threshold. Unfortunately, at this point of the investigation, part of the simulation equipment was required for use in service and it was therefore not possible to examine the performance of the special filter arrangement in detail. However, the performance of the special arrangement — as well as that of the 4·5 MHz low-pass filter — was examined in field measurements on an s.h.f. link, described in the next section.

5. Field measurements

To supplement the laboratory simulation tests some measurements were carried out — in co-operation with staff of the Post Office and of Designs Department and Communications Department of the BBC — on a series of Post Office temporary s.h.f. links from Birmingham to Purdown (near Bristol).

For the investigation the normal BBC p.c.m.-sound multiplex signal was routed by cable from Sutton Coldfield to Birmingham. Communications Department staff at Sutton Coldfield adjusted the level of the baseband multiplex signal — and hence the f.m. carrier deviation on the link — as required for the tests. A waveguide attenuator in the s.h.f. input of the receiving apparatus at Purdown was used to simulate fading. The demodulated signal, after appropriate amplification to compensate for reduced deviation, was applied to BBC 6·336 Mb/s de-multiplex equipment, and the operation of the signal mute in this apparatus was taken as the criterion of system failure. For this exercise the error rate at muting was about 3·5 in 10^3.

Pre- and de-emphasis networks to the CCIR specification were not available for the link, so all the field measurements at Purdown were made with the link

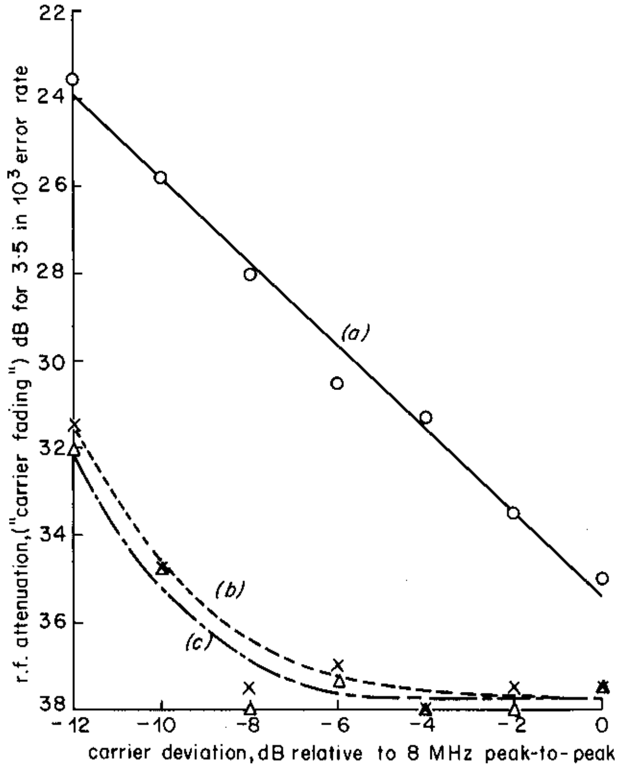

Fig. 10 - R.F. attenuation in link for an error rate of 3·5 in 10,^{3} plotted as a function of carrier deviation. Link not degraded, no pre- and de-emphasis

(a) No low-pass filter
(b) With 4·5 MHz low-pass filter
(c) With optimum-low-pass filter (plus 5·5 MHz filter)

unemphasised. Measurements were made under three test conditions: with the data stream nominally unimpaired; with link degradation imposed at Sutton Coldfield corresponding to a $2T$ pulse K-rating of about 3%;[9] and with link degradation imposed at Sutton Coldfield corresponding to a pulse-to-bar ratio (of pulse-and-bar test) of 80%.[9]

Fig. 10 shows the results obtained with the data waveform nominally unimpaired; the r.f. attenuation (controlled at Purdown) for a data error-rate of 3·5 in 10^3 is plotted as a function of carrier deviation (controlled at Sutton Coldfield) for (a) no baseband filtering, (b) 4·5 MHz low-pass filtering and (c) 'optimum' low-pass filtering. Curves (a) and (b), Fig. 10, are in general, similar to the corresponding results for the simulation shown in Figs. 8 and 9, though the improvement in fading margin resulting from use of the 4·5 MHz low-pass filter is somewhat greater in the tests on the link. The latter effect is presumably due, at least in part, to differences in the r.f. noise spectrum in the two cases.

The results of the field measurements using the optimum filter, curve (c), show an improvement of about 0·5 dB compared with those using the 4·5 MHz low-pass filter.

Figs. 11 and 12 show the corresponding results obtained with deliberate link degradation introduced as already described. The two sets of data are very similar; compared with the results given in Fig. 10, both show a further reduction of fading margin of 3 to 4 dB in the absence of low-pass filtering and of 0·5 dB to 2 dB with filtering. Thus, in general, the filters give a greater gain on the degraded rather than on the undegraded data signals; for example, the improvement obtained using the 4·5 MHz filter at a deviation of 8 dB below 8 MHz peak-to-peak was about 11 dB on the degraded data, compared with about 9 dB for undegraded data.

Figs. 11 and 12 again indicate a slight preference for the specially designed filter arrangement but the advantage appears to be no more than 0·5 dB to 1 dB.

During the field investigation it was noticed that, as the r.f. attenuation was increased and the muting condition was approached, the subjective effect of errors on the reproduced sound-programme was generally more impulsive or 'spitty' when a baseband low-pass filter was included. Though the circumstances of the field measurements did not allow a full investigation of this feature at the time, the effect is perhaps not surprising since p.c.m. failure with the low-pass filtering in circuit occurs at the f.m. improve-

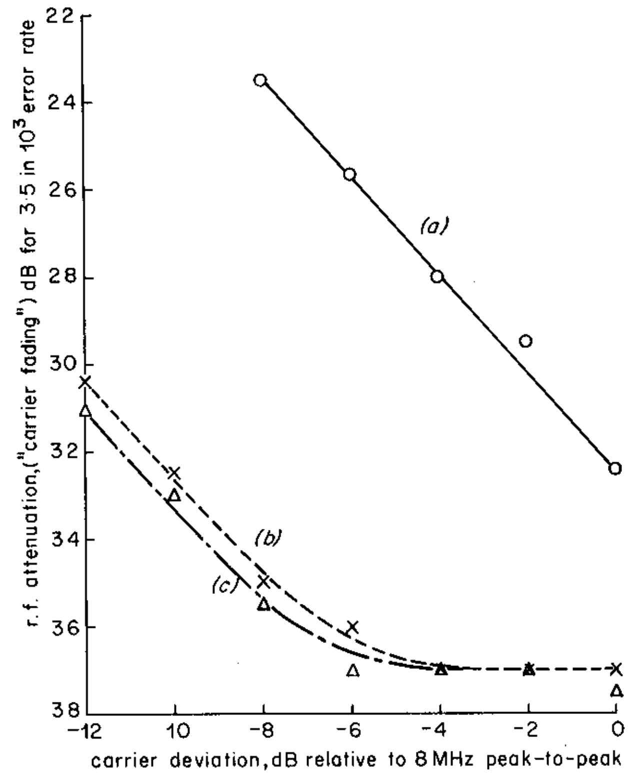

Fig. 11 - R.F. attenuation in link for an error rate of 3·5 in 10^3, plotted as a function of carrier deviation. No pre- and de-emphasis. 2T pulse K-rating of link, 3%.

(a) No low-pass filter
(b) With 4·5 MHz low-pass filter
(c) With optimum-low-pass filter (plus 5·5 MHz filter)

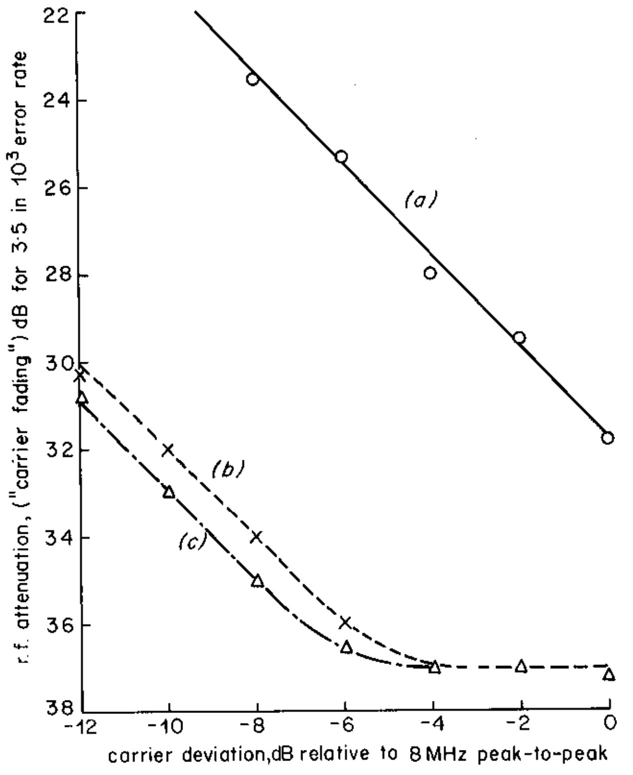

Fig. 12 - R.F. attenuation in link for an error rate of 3·5 in 10^3, plotted as a function of carrier deviation. No pre- and de-emphasis. Pulse-to-bar ratio on link 80%.

(a) No low-pass filter
(b) With 4·5 MHz low-pass filter
(c) With optimum-low-pass filter (plus 5·5 MHz filter)

ment threshold (i.e. it is due to carrier failure) for much of the range of deviation used in the tests; in this condition, the f.m. link noise is itself impulsive rather than continuous in character.

6. Conclusions

The Post Office have noted, that where Tariff V1 video circuits are used at full deviation for 6·336 Mb/s p.c.m. sound, the resulting r.f. spectrum is such that the carrier-failure alarm in some equipment gives a false indication; further, that the risk of causing adjacent channel interference is increased. As a remedy they recommend that the carrier deviation for p.c.m. sound is reduced 8 dB below the 8 MHz peak-to-peak which is normal for video.

Examination of the relevant r.f. spectra has confirmed that reducing deviation is indeed effective both in increasing the r.f. energy near the carrier rest frequency (thus reducing anomalous operation of carrier failure alarm circuits) and in reducing the sideband energy at the channel edge (consequently reducing risk of causing adjacent channel interference). However, reducing deviation also reduces the fading margin on the link. Measurements indicate that, with no baseband filters in circuit other than the normal CCIR video pre- and de-emphasis, 8 dB reduction of deviation gives a reduction of fading margin of about 7 dB. Theoretical consideration has indicated that, in these circumstances, the margin can be largely restored by restricting the bandwidth of the baseband data channel at the receiving terminal.

Measurements have confirmed that, in the circumstances described above, the fading margin can be restored in practice to within 1 dB or so of the value for full deviation by including a group-delay-corrected, 4·5 MHz low-pass filter in the baseband channel of the receiving terminal. If a baseband low-pass filter already exists in the receiving terminal equipment, the improvement obtained with a 4·5 MHz low-pass filter will, of course, be correspondingly reduced. Nevertheless, it will be sufficient to bring the fading margin within about 1 dB of the ultimate limit set by carrier failure.

If the reduction of deviation adopted were 6 dB, rather than 8 dB, introduction of the 4·5 MHz filter would restore the fading margin practically to the limit set by f.m. carrier failure.

A specially designed filter gave marginally better results, 0·5 dB to 1 dB more recovery of fading margin at low deviation; however the special filter actually used was of a simplified design and required an additional low-pass filter to maintain attenuation at high frequencies. A single filter having the appropriate overall characteristics would necessarily be more complicated and, in view of the marginal improvement in performance, compared with the 4·5 MHz low-pass filter, is probably not justified.

It is recommended therefore that, where 6·336 Mb/s p.c.m. sound signals are to be transmitted at reduced deviation on Post Office Tariff V1 circuits, the CCIR pre- and de-emphasis be retained and the received baseband data be passed through a group-delay-corrected 4·5 MHz low-pass filter.

7. Acknowledgements

The authors acknowledge their indebtedness to staff of the Post Office, and to colleagues in BBC Communications and Designs Departments for co-operation at various stages of the investigation.

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